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MODELING THE DISPERSION OF NO_x AND SO_2 EMISSIONS FROM A PROPOSED BIOGAS PRODUCING FACILITY

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ABSTRACT

This study aims to model the dispersion of two pollutants: nitrogen oxides (NO_x) and sulfur dioxide (SO_2) from an onsite biogas fueled generator by using CALPUFF modeling system. CALPUFF is a non-steady state puff simulating software that takes into account, meteorological data, terrain data and land use data, to effectively simulate dispersion from a given source. These data are taken from the different governmental and accredited organizations and used in conjunction with CALPUFF. Results showed a wider dispersion of both pollutants in January as supposed to June. This was due to rapid changes of wind's speed and directionin the month of January. It was also discovered that the emission results were well below the point of impregnation (POI) limits set by the Ministry of Environment for its 24 hour, 1 hour and 30 minute averaging time periods of exposure. The findings of this study reveal that the proposed facility's operation is in compliance with the Ontario regulations and that it should be able to operate in accordance with them, in the winter and summer seasons.

Keywords: Biogas; CALPUFF; Dispersion; Modeling; Nitrogen Oxides; Sulfur Dioxide

1. Introduction

Biogas as a fuel source leads to the production of certain pollutants. Among these are nitrogen oxides (NO_x) and sulphur dioxide (SO_2) which are very dangerous to flora and fauna. Nitrogen oxides from ambient exposures can have a variety of adverse health effects on humans. Some effects on human health from NO_x include inflammation of the breathing pathways, which results from an exposure to a concentration of 1-2 ppm (Stackelberg, 2011). NO_x also has effects on the environment. Some effects on the environment include causing blooming of algae in water bodies, which increases the toxicity levels in them, along with a large amount of deposition of nitrogen in the soil that reduces its fertility (Stackelberg, 2011). Sulphur dioxide also has many adverse health effects on humans, including wheezing and irritation of the airways. If the exposure times are long enough, then irritation of both the pulmonary and cardiovascular systems can cause diseases as well as a severe occurrence of both occurring (Bruce *et al.,* 2000). Sulfur dioxide emitted, causes most

environmental damage by helping to create acid rain. This rain waters the vegetation and corrodes the helpful nutrients in the soil as well as the flora themselves by reducing the amount of nutrients available to them for survival. Sulfur dioxide also directly reduces the metabolism of plants, which again reduces its survivability (Enviropedia, 2013).

The proposed facility to be located in Napanee, Ontario, will attempt to produce biogas from organic matter and then use the produced gas as a fuel source to an onsite generator. This generator will be used to produce onsite electricity for the landfill mechanisms. This production of electricity, however will lead to various emissions such as particulates and the aforementioned pollutants. For example, in constructing this plant, the limits set by the Ministry of Environment (MoE) for NO_x had to be taken into account. The limits set were 200 $\mu g\ m^{-3}$ and 400 $\mu g\ m^{-3}$ for 24 hours and 1 hour of exposure (Ontario Ministry of Environment, 2012).

To model these environmental pollutants, CALPUFF is used. The CALPUFF model evaluates dispersion of compounds and plume trajectories on the basis of non-steady state characteristics (Dresser and Huizer, 2011) including the meteorological data such as wind vectors and terrain data (Vieira de Melo *et al.,* 2012). The model can also predict dispersion over complex terrain, but however is more accurate and reliable if the domain is large (Cui *et al.,* 2011). Furthermore, other research papers have been done in conjunction with this software to model SO_2 from a power plant (Levy *et al.,* 2002) and from industrial heating sources (Levy *et al.,* 2000). Research has also been done on the dispersion of NO_x using CALPUFF.The emissions sources modeled included cement, and clay industrial plants in the Mediterranean basin (Ghannam and El-Fadel, 2013) as well as the modeling of nitrogen dioxide from a similar fueled plant of biomass (Curci *et al.,* 2012).

This research intends to measure the extent to which nitrogen oxides and sulfur dioxide emissions from a proposed plant in Fredericksburg affect the surrounding environment, which includes lush vegetation as well as human entities. It will also attempt to compare these dispersion results with the MoE standards and regulations on the point of impregnation (POI) limits for these pollutants in ambient air. Hence the research will also add to the existing knowledge base on emission attributes of these two pollutants from an onsite biogas fueled generator.

2. Materials and methods

2.1. Description of the study area

The study area for this project is a landfill for solid wastes situated in the town of Napanee, Lot 1, Concession 2, former Town of South Fredericksburgh, in the County of Lennox and Addington (Trow Associates Inc., 2014). Figure 1 is a map that indicates the specific location of the study area. The yellow marker tagged as the disposal site, shows the specific location of the study area. As seen from the map, the latitudinal and longitudinal locations are 44.135467°N and 76.942092°W, respectively.

The size of the town of Napanee is $8.9 \times 10^4\ m^2$ with the terrain having heights up to almost a 100 m (Trow Associates Inc. 2014). The landfill site has been operating for over 40 years and can keep on operating for an additional 50 years, as only close to 10% of the total site capacity has been used for disposal of solid wastes up till date (Trow Associates Inc., 2014). The population of the town of Napanee is about 7,221 inhabitants as of the year 2011, consisting of 6,330 households, according to Statistics Canada (Statistics Canada, 2014a; Statistics Canada, 2014b).

There are several locations close to the study area; these locations will be receptors of the possible emissions from the plant. These include the Hog farm located approximately 400 m north of the site, Haybun located approximately 1300 m north of the site, a residence located approximately 1400 m east of the site and two other residences located 600 m south east of the site and 920 m south of the site receptively (Trow Associates Inc., 2014).

Figure 2 shows the land use of the study area. There are four major ramifications in which the land is put to use. A large portion of the land area is covered by water. Another large portion of the land area is covered by forest while the rest is being used for agriculture with a very little portion used for urban buildings.

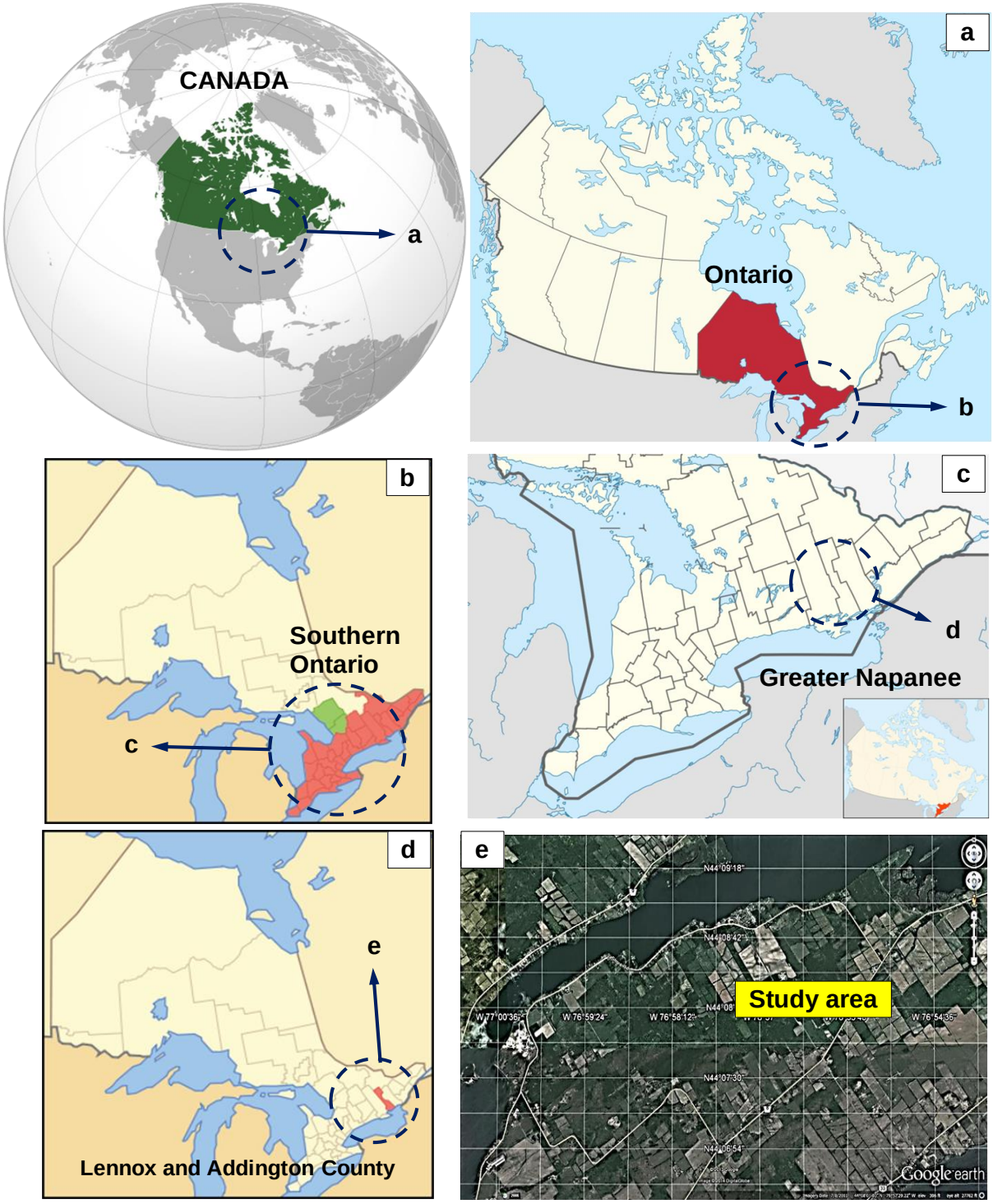

Figure 1. Location of the study area on the map of Canada

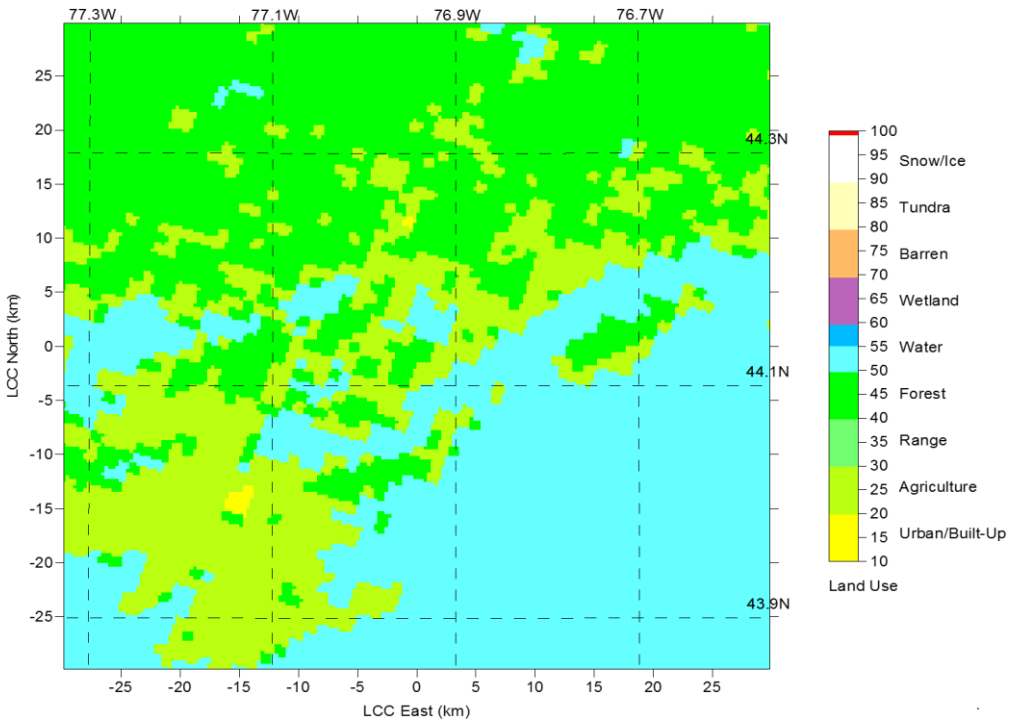

Figure 2. Land use of the study area

2.2. Surface data

The dispersion of pollutants is not only affected by the terrain, but also by the wind vectors. To account for this factor, upper air and surface meteorological data was retrieved and used in the modeling software. The surface meteorological data was taken from the Government of Canada, historical climate database (Government of Canada Historical Climate Database, 2014). The station from which the data was obtained was the Toronto Pearson International Airport surface station. This station was chosen as it was in close proximity to the point of interest. Two sets of dates were chosen to model the emissions in the seasons of winter and summer. These dates were from January 9, 2013 to January 11, 2013 and June 9, 2013 to June 11, 2013. These dates were chosen initially as there were full sets of meteorological data available for each, however the final choice would also rely on whether or not full sets of upper air data were available for each chosen date. This surface data was then converted to a specific format so as to make it compatible with the SMERGE processor. This would then produce an output so that the data can be incorporated into the CALMET program. A summary of the surface meteorological data is found in Table 1**.** The table lists information on the Station Name, UTM, Latitude, UTM Longitude, Elevation, Climate ID, WMOID and the TC ID.

Table 1. Surface meteorological data

Parameter	Values
Station Name/Location	Toronto Pearson International Airport, Ontario
UTM Latitude	43.67722 °N
UTM Longitude	79.63056 °W
Elevation	173.40 m
Climate ID	6158733
WMO ID	71624
TC ID	YYZ

2.3. Upper air data

Data for upper air attributes were acquired from the ESRL/NOAA website (NOAA/ESRL Radiosonde Database, 2014). The Buffalo radiosonde station was selected as it experienced similar upper air characteristics to that of the point of interest and the surface station used. The station had to also be geographically close to the point of interest and surface station. Keeping the days used for retrieving the surface meteorological data as a constant variable, upper air data was extracted from the website database for use in the Read62 processor. This processor converted the meteorological data into a format that could be used in conjunction with the CALMET processor. Again the data was selected for the specified days based on the fact that full sets of upper air meteorological data were available from this database and also the aforementioned surface air database. Table 2 shows a summary of the upper air meteorological data retrieved and used for the modeling software. The table lists the UTM latitude, longitude, elevation, WBAN identifier, WMO ID, and INIT of the Buffalo radiosonde station.

Table 2. Upper air meteorological data

Parameter	Values
Station Name/Location	Buffalo Airport NY US
UTM Latitude	42.93^{o}N
UTM Longitude	-78.73^{o}W
Elevation	218 m
WBAN	14733
WMO ID	72528
INIT	BUF

2.4. CALPro modeling system

The CALPro software is a very powerful tool for modeling air quality and was built by the atmospheric studies group. CALPro can be used to analyze and assess pollution effects and the impacts on nearby locations of a particular study area. The CALPro modeling system is also capable of taking into consideration, the complex terrain features, timely emissions of various emission sources and wind effects resulting from weather conditions of a particular study area. This helps it adequately analyze and create realistic models of emission dispersions (Abdul-Wahab *et al.,* 2014).

There are three major components of the CALPro modeling system: CALMET, CALPUFF and CALPOST. In addition to the above-mentioned components, it also has a pre-processing system, which consists of processors for processing surface meteorological, upper air meteorological, precipitation, geophysical and overwater data.

The post-processing packages are PRTMET and CALPOST. These packages are used for the processing of models simulated by CALMET andCALPUFF respectively. CALMET is a meteorologicalmodel that helps to generate hourly, wind and temperature fields in the study area of interest. It consists of two modules namely the micrometeorological module and the diagnostic wind field module for analysis of overland and overwater regions (Abdul-Wahab *et al.,* 2014).

Requirements for the diagnostic module are geophysical and other prognostic or observed data as inputs. The observational data consists mainly of upper air and surface data and needs to be processed in a particular file format before they can be used as inputs into CALMET. The data can then be imputed in three ways: an initial guess field, step one wind field, or as observational data. Wind field produced by prognostic models i.e. MM5, WRF and MM4 canbe used as input into CALMET (Abdul-Wahab *et al.,* 2014).

CALPUFF is a Lagrangrian Gaussian puff model that runs its modeling based on a non-steady-state procedure. This is due to the fact that while it runs, it takes into consideration the results from the subsequent times

during the subsequent runs. It can be used to model for multi-layers and multi species of a particular study area with respect to the contaminants of interest. It requires the 3D model produced by the CALMET processor and also takes into consideration the spatial and temporal changes that occur in the meteorological domain of study within a particular modeling period. CALPUFF is then used to generate an output file that gives the varying hourly emissions of various emission sources, in concentration units, at every grid point of the meteorological domain at different heights. Often the first layer of height is usually considered for the results (Abdul-Wahab *et al.,* 2014).

The output that is produced by CALMET is then used as an input for the CALPOST processor. CALPOST is a post processor used to process the output file from CALPUFF (which contains concentrations, meteorological data and deposition fluxes). CALPOST summarizes the simulation results and arranges the results in descending order from the highest concentrations of dispersion to the lowest with corresponding times and coordinates in the meteorological domain (Abdul-Wahab *et al.,* 2014).

2.5. Operation of CALPro

The geophysical and meteorological data were initially made into a common file by using the meteorological domain model inputs shown in Table 3.CALPro was used for processing the Terrain, Land use and coastline data obtained from the SRC website to give a GEO.DAT file as output. By using the READ62 and SMERGE pre-processing programs, upper air and surface meteorological data were processed to produce UP.DAT and SURF.DAT files respectively.

Table 3. Model input information for the domain of study

Parameter	Values
Projection	LCC
LCC latitude of origin	43.866667 ^{o}N
LCC longitude of origin	78.816667 ^{o}W
Latitude 1	10 ^{o}N
Latitude 2	50 ^{o}N
False Easting	0
False Northing	0
Continent/Ocean	North America
Geoid-Ellipsoid	North American Datum of 1983: GRS 80
Region	Canada
DATUM code	NAR-B
X (Easting)	-30 km
Y (Northing)	-30 km
Number of X grid cells	200
Number of Y grid cells	200
Grid spacing	0.3 km
Number of vertical layers	9
Cell face heights (m)	0-20, 20-50, 50-100, 100-150, 150-200, 200-300, 300-500, 500-1000, 1000-2000
Base time zone	UTC-05:00 Eastern time
UTM zone	17
Hemisphere	Northern

The GEO.DAT, SURF.DAT and UP.DAT files where then used as input for running CALMETand this produced a 3D meteorological model of the study area domain. The output from the CALMET processor was further processed using PRTMET to visually observe the variations in vectors of the wind field as time changed, in the

domain. Furthermore, the CALMET.DAT file was processed by CALPUFF for the determination of total suspended particles over time. The output of this process, CALPUFF.DAT file,was then used as an input for the CALPOST processor to produce contour plots over a one hour averaging period for total suspended particles in a day and a summarized list of the concentrations in a descending order, over a one hour and twenty four hour averaging period. This overall process was carried out for all the emission sources in the study area and then compared to the Ontario's Ministry of Environment twenty-four hour concentration standard. The one-hour averaging concentrations are first converted to the thirty-minute equivalent averaging values using the equation below:

$$(30 \text{ minute concentration}) = (1 \text{ hour concentration}) \times (1 \text{ h}/0.5 \text{ h})^{0.28} \quad (1)$$

It is also compared to Ontario's Ministry of Environmentthirty-minute concentration standard.

2.6. Emission data

There are three main types of emission sources. These include the point source, the line source and the area/volume source. For the purpose of this study, because we want to analyze the emissions resulting from the operation of the generator in the plant, we will consider only the point source as the emission source. Every other emission from the landfill waste decomposition site will be disregarded.

The methane-powered generator in the facility is a point source that will be a major source of emission of air contaminants into the atmosphere. As discussed in the process of the facility section, in cases where there is malfunction of the generator or inadequate production of biogas, the back-up flare will be used as an alternative to generate electricity thereby making it another source of emission to the atmosphere. Hence there two major sources of emission for consideration in this study (the generator and the flare) (Trow Associates Inc., 2014).

For the purpose of this study, two air contaminants will be of interest, SO_2 and NO_x (NO_x comprises of NO and NO_2 in various proportions). For each of these contaminants, the volumetric flow, temperature, diameter, height of emission, coordinates and maximum emission velocities for each emission source are all shown in Table 4.

Table 4. Emission data

Source type	Source ID	Flow rate ($m^3\ s^{-1}$)	Temperature (°C)	Diameter (m)	Height above roof (m)	Height above grade of each point source (m)	Source coordinates (x,y)	Averaging periods (hrs)	Emission for NO_x ($g\ s^{-1}$)	Emission for SO_2 ($g\ s^{-1}$)
Point	Stack	0.68	513.8	0.2	2	2	(0,0)	0.5	0.27	0.047
Flare	Flare	0.71	760	1.5	10.2	12.2	(0,0)	0.5	0.026	0.0037

2.7. Operation of the facility

2.7.1. Biogas and electricity production

Methane is produced as a by-product when residential source separated organic (SSO) waste decomposes anaerobically. The SSO is supplied by several residential waste diversion programs in Ontario. The methane gas given off is used as an energy source for the methane powered generator for generation of electricity for the feed-in tariff (TIF) program. The source separated organic wastes are transported to the site in sealed 20 tonne dump vehicles. The wastes are then covered with soil by a dozer, which will promote anaerobic decomposition from which biogas rich in methane can be obtained. As the decomposition process goes on, methane is encapsulated and used as fuel for the generator to produce electricity.

This process is accompanied with the emission of contaminants that are essentially the products of combustion, other organic compounds and odor. However, the design of the operation incorporates

procedures to reduce the expected emissions of air contaminants and smell from activities such as the unloading, processing and decomposition of organic material.The residential SSO waste will be brought into the site in a 3-4 hour period on a daily basis. This organic waste is then offloaded into an organic pit with the help of a bulldozer. Also, on a daily basis, soil is used to cover the organic waste to help reduce the smell resulting from decomposition.

As new organic wastes come into the facility, they are placed on top the already existing layer of soil used to cover the previous organic waste. This process is then continually repeated until a desired contour level has been attained. As the composting process goes on, Leachate (liquid that moves through or drains from solid organic waste) (Sunshine, 2014) will travel through the organic waste in a downward direction towards the ground. As a result of this, an impermeable membrane is installed underneath the organic material to restrain the leachate from going into the ground.

A water retention pond will be made available for the management of leachate and water waste due to the operation. The decomposition of the organic waste will give off biogas and thus a gas collection system will be installed for this purpose.The collection system will consist of series of pipes installed within the organic waste material. The methane gas collected is then fed to the methane-powered generator. This generator generates electricity that will be eventually fed to the Hydro One distribution system.

The final compost material obtained at the end of the process will then be processed (extraction, screening and testing for final use). To restrain litters from going offsite, a mobile fence will be provided during the waste offloading operation.There will be no additional wastes generated by the operation; neither will the process involve the use of any materials that are hazardous or toxic.

In a case where the power generator fails to function properly or maintenance is being carried out, or there is excess of biogas being produced, the operation will have an alternative of using a backup flare that is capable of burning 100% of the biogas being produced. However if the flare is in operation, noise will be generated; this also applies to the methane-powered generator(Trow Associates Inc., 2014). A flow diagram of the process is shown in Figure 3.

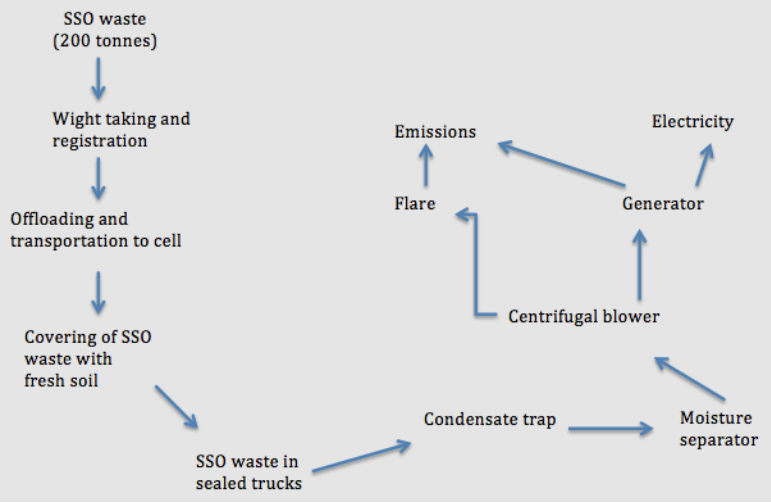

Figure 3. Process flow diagram

2.7.2. Operating schedule

Source separated organic waste material is scheduled to come into the site within a 3-4 hour period, each day, five days (Monday through Friday) in a week. The material will be brought in sealed dump trucks each weighing 20 tonnes. There will be approximately twelve dumps coming into the site. The biogas extraction

operation will run for 24 hours, each day of the week. Meanwhile, the back-up flare will run as an alternative in situations where the generation of biogas exceeds the generator capacity or isnot sufficient for the generator to run.

3. Results and Discussion

The emission dispersions for NO_x and SO_2in a biogas production site, situated in the town of Napanee were modeled in this study. Two periods of the year (winter period and summer period) were considered for examination as a specific day was chosen to represent the two periods. For the wintertime, the chosen day was the 10th of January 2013, and for the summer time, 10th of June 2013. Hourly concentrations of the air contaminants (NO_x and SO_2) were obtained between the hours of 0:00 HST to 23:00 HST for a 1-hour averaging period and a 24-hour averaging period. Results that were obtained were converted to 30-minute averaging periods for the purpose of comparison with the Ministry of Environment's allowable standards.

Observations from the wintertime indicate more wind effects on the dispersions and the wind vectors indicate aggressive behavior of wind motion in the atmosphere leading to higher dispersions as seen in Figures 4 and 5.

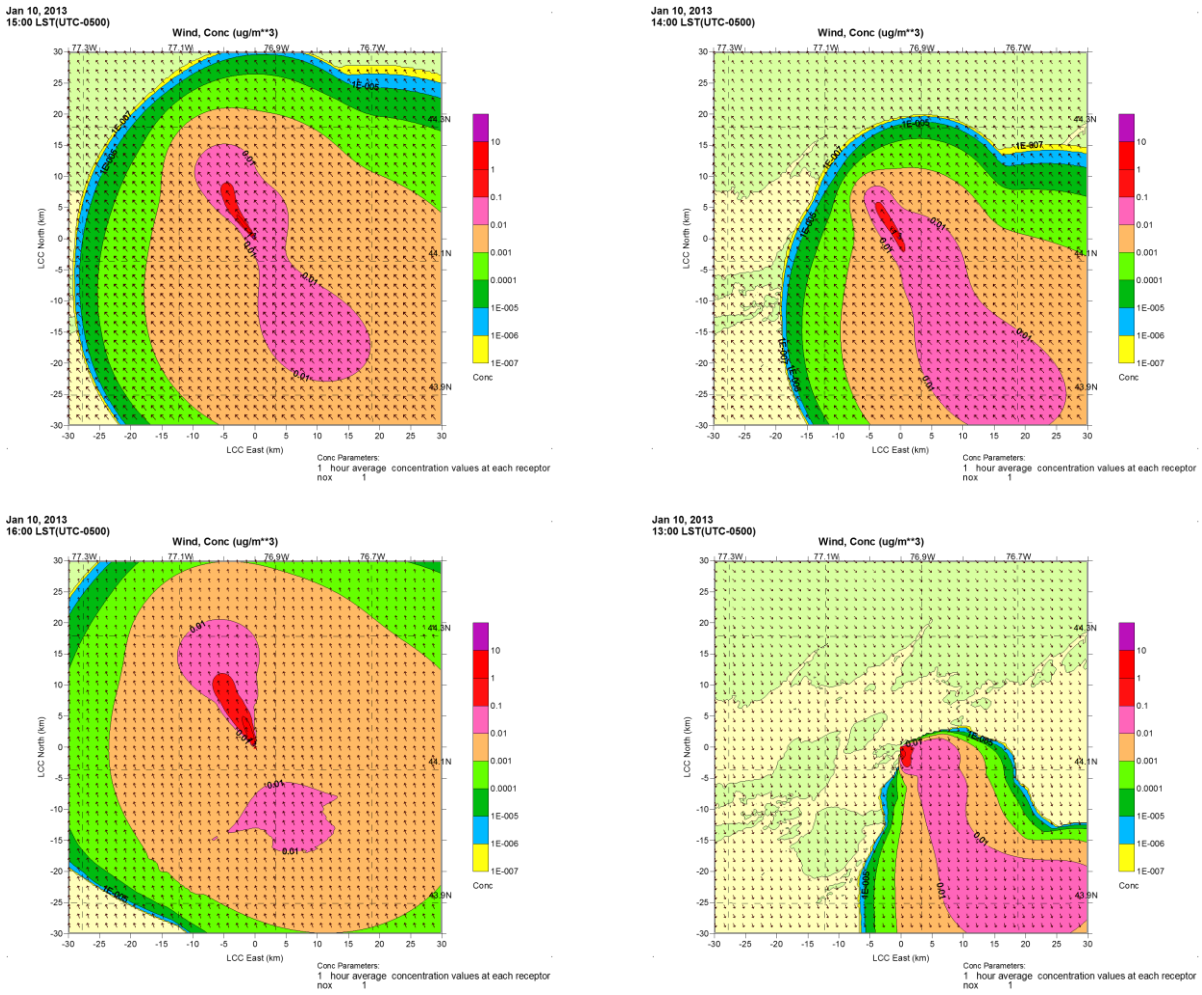

Figure 4. NO_x emission dispersion in the wintertime

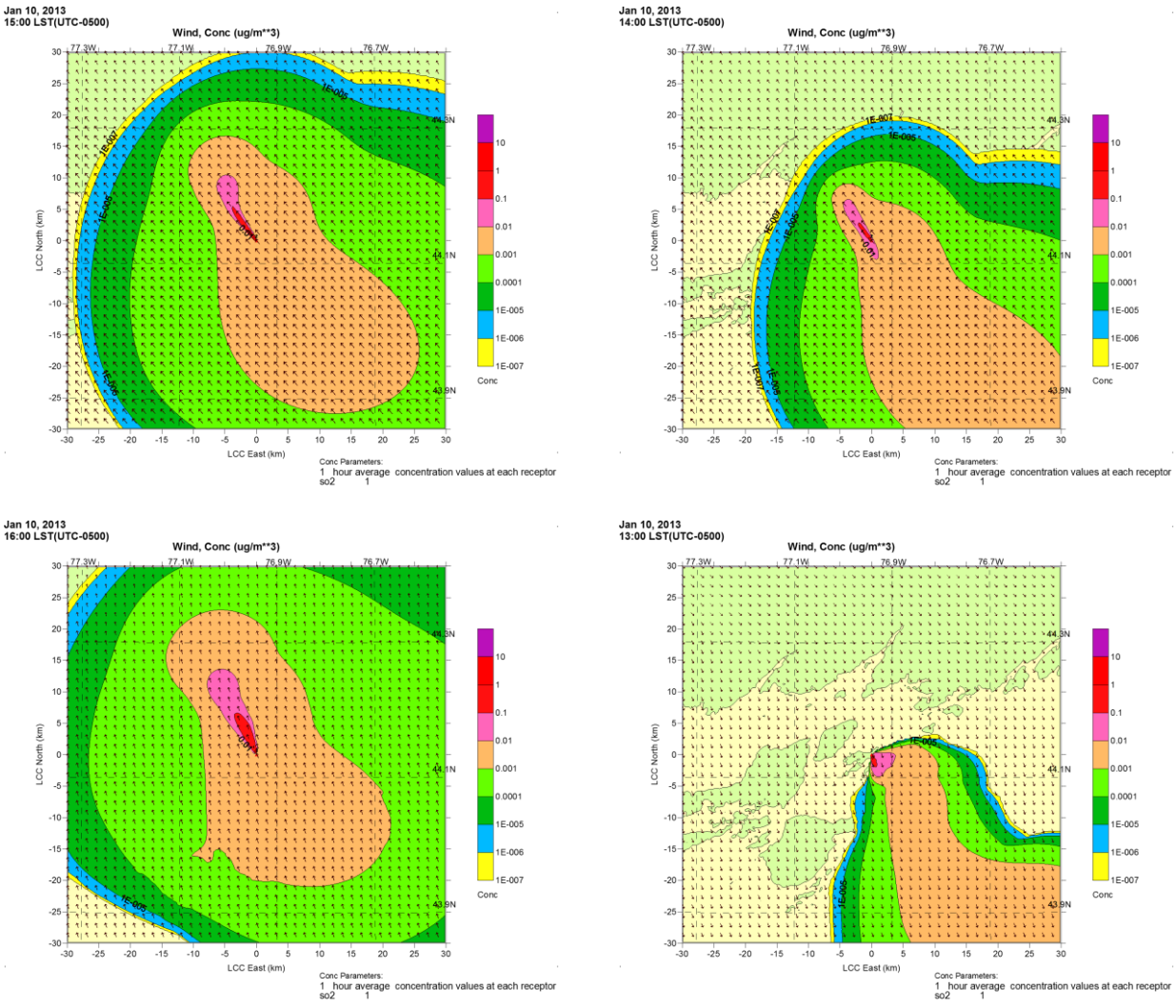

Figure 5. SO_2 emission dispersion in the wintertime

The results of interest were the maximum values of concentrations obtained at specific hours. During the wintertime, the NO_x and SO_2 maximum concentrations were recorded in hours 13:00, 14:00, 15:00 and 16:00 as shown in Figures 4 and 5. It can also be seen from the figures, that as time progresses; a larger portion of the meteorological domain gets covered with the dispersion clouds, as hour 16:00 HST has the larger dispersion cloud while hour 13:00 HST has the smallest dispersion cloud. This is mainly due to the change of the wind direction together with the wind speed during these hours. The figures also indicate the movement of the wind vectors from the southeastern direction to the northwestern direction within these four hours.

For the wintertime, the highest concentrations for NO_x were 67.40 µg m^{-3} for a 30-minute averaging period, 55.51 µg m^{-3} for a 1-hour averaging period and 4.79 µg m^{-3} for a 24-hour averaging period (Table 5).

For SO_2, the highest concentrations were 11.689 µg m^{-3} for a 30-minute averaging period, 9.63 µg m^{-3} for a 1-hour averaging period and 0.83 µg m^{-3} for a 24-hour averaging period. The coordinates that describe the positions on the meteorological domain, where these concentrations were determined are shown in Tables 6 and 7.

Table 5. Comparison of NO_x and SO_2 emitted concentrations over 30-minute, 1-hour and 24-hour averaging periods to the Ministry of Environment standards

January 10, 2013				June, 10, 2013			
Contaminant	MC[a] (μg m^{-3})	AP[b] (hours)	MoE[c] limit (μg m^{-3})	Contaminant	MC (μg m^{-3})	AP (hours)	MoE limit (μg m^{-3})
	67.404	0.5	500		49.170	0.5	500
NO_x	55.513	1	400	NO_x	40.496	1	400
	4.786	24	200		11.117	24	200
	11.689	0.5	830		8.451	0.5	830
SO_2	9.627	1	690	SO_2	6.960	1	690
	0.828	24	275		1.912	24	275

[a] Maximum concentration, [b] Averaging period, [c] Ministry of Environment.

Table 6. Top 10 concentrations of NO_x and SO_2 in the wintertime for 1-hour and 24-hour averaging periods

No	1-hour average SO_2 concentrations				24-hour average SO_2 concentrations		
	Time (HH:MM)	Concentration (μg m^{-3})	Coordinates (km)		Concentration (μg m^{-3})	Coordinates (km)	
			X	Y		X	Y
1	15:00	9.627	-0.15	0.15	0.828	-0.15	0.15
2	14:00	9.319	-0.15	0.15	0.231	0.75	-0.45
3	16:00	4.243	-0.15	0.45	0.221	0.15	-0.45
4	13:00	2.998	0.15	-0.45	0.220	0.15	-0.15
5	22:00	2.973	-0.45	0.15	0.209	-0.15	-0.45
6	1:00	2.408	0.15	-0.15	0.206	0.75	-0.45
7	2:00	2.393	0.75	-0.45	0.162	-0.45	-0.45
8	6:00	2.319	0.45	0.15	0.160	-0.75	-0.45
9	15:00	2.261	-0.45	0.45	0.153	0.45	0.15
10	21:00	2.081	-0.75	0.45	0.145	1.35	0.75
No	1-hour average NO_x concentrations				24-hour average NO_x concentrations		
	Time (HH:MM)	Concentration (μg m^{-3})	Coordinates (km)		Concentration (μg m^{-3})	Coordinates (km)	
			X	Y		X	Y
1	15:00	55.513	-0.15	0.15	4.786	-0.15	0.15
2	14:00	54.044	-0.15	0.15	1.341	0.75	-0.45
3	16:00	24.703	-0.15	0.45	1.288	0.15	-0.45
4	13:00	17.463	0.15	-0.45	1.272	0.15	-0.15
5	22:00	17.166	-0.45	0.15	1.216	-0.15	0.45
6	1:00	13.899	0.15	-0.15	1.190	0.75	0.45
7	2:00	13.874	0.75	-0.45	0.939	-0.45	0.45
8	6:00	13.415	0.45	0.15	0.924	-0.75	0.45
9	15:00	13.107	-0.45	0.45	0.886	0.45	0.15
10	21:00	12.010	-0.75	0.45	0.841	1.35	0.75

Observations from the summertime indicate much lower dispersions as the wind vectors indicate a much less aggressive behavior in the wind motion when compared to the wintertime, leading to less dense dispersion clouds as seen in Figures 6 and 7. This has been observed from the real measurements of the wind speed and directions. Also, it has been indicated by the model results. Again the results of interest for the summertime were the maximum values of concentrations obtained at specific hours. During the summertime, for both NO_x and SO_2, the maximum concentrations were recorded in hours 2:00, 5:00, 8:00 and 9:00 as shown in Figures

6 and 7 for NO_x and SO_2, respectively. Again as time passes the dispersion clouds become denser as seen in Figures 6 and 7 for the case of NO_x and SO_2 respectively. Windrose diagrams for January 10, 2013, and June 10, 2013 are shown in Figure 8.

Table 7. Top 10 concentrations of NO_x and SO_2 in the summertime for 1-hour and 24-hour averaging periods

No	1-hour average SO_2 concentrations				24-hour average SO_2 concentrations		
	Time (HH:MM)	Concentration ($\mu g\ m^{-3}$)	Coordinates (km)		Concentration ($\mu g\ m^{-3}$)	Coordinates (km)	
			X	Y		X	Y
1	5:00	6.958	-0.45	-0.15	1.912	-0.45	-0.15
2	2:00	6.413	-0.45	-0.15	0.713	-0.15	-0.15
3	9:00	5.974	-0.15	-0.15	0.562	-0.75	-0.45
4	8:00	5.947	-0.15	-0.15	0.474	-1.35	-0.75
5	3:00	5.890	-0.45	-0.15	0.468	-0.75	-0.15
6	19:00	5.160	-0.45	-0.15	0.370	-1.35	-0.45
7	1:00	5.120	-1.35	-0.75	0.320	-1.05	-0.45
8	0:00	4.749	-0.75	-0.45	0.263	-1.95	-1.05
9	16:00	4.582	-0.45	-0.15	0.230	-1.05	-0.15
10	1:00	4.580	-0.75	-0.45	0.172	-1.65	-0.45
No	1-hour average NO_x concentrations				24-hour average NO_x concentrations		
	Time (HH:MM)	Concentration ($\mu g\ m^{-3}$)	Coordinates (km)		Concentration ($\mu g\ m^{-3}$)	Coordinates (km)	
			X	Y		X	Y
1	5:00	40.496	-0.45	-0.15	11.117	-0.45	-0.15
2	2:00	37.131	-0.45	-0.15	4.147	-0.15	-0.15
3	9:00	34.751	-0.15	-0.15	3.248	-0.75	-0.45
4	8:00	34.623	-0.15	-0.15	2.752	-1.35	-0.75
5	3:00	34.112	-0.45	-0.15	2.727	-0.75	-0.15
6	19:00	30.051	-0.45	-0.15	2.156	-1.35	-0.45
7	1:00	29.685	-1.35	-0.75	1.860	-1.05	-0.45
8	0:00	27.375	-0.75	-0.45	1.528	-1.95	-1.05
9	16:00	26.692	-0.45	-0.15	1.341	-1.05	-0.15
10	1:00	26.410	-0.75	-0.45	1.005	-1.65	-0.45

The wind exhibits a gentle behavior during the summertime when compared to the wintertime. This explains the reduced effects on the dispersion between the two seasons since less dense dispersion clouds are produced in the summertime. For the summertime, the highest concentrations for NO_x were 49.170 $\mu g\ m^{-3}$ for a 30-minute averaging period, 40.50 $\mu g\ m^{-3}$ for a 1-hour averaging period and 11.12 $\mu g\ m^{-3}$ for a 24-hour averaging period (Table 5). For SO_2, the highest concentrations were 8.451 $\mu g\ m^{-3}$ for a 30-minute averaging period, 6.96 $\mu g\ m^{-3}$ for a 1-hour averaging period and 1.91 $\mu g\ m^{-3}$ for a 24-hour averaging period. It is noted that concentrations (for both NO_x and SO_2) are lower in summer comparing to winter just only at the first two top concentrations. The coordinates for the corresponding concentrations mentioned above are shown in Tables 6 and 7. But on the rest of the top concentrations, it can be seen that the concentrations were higher is summer.

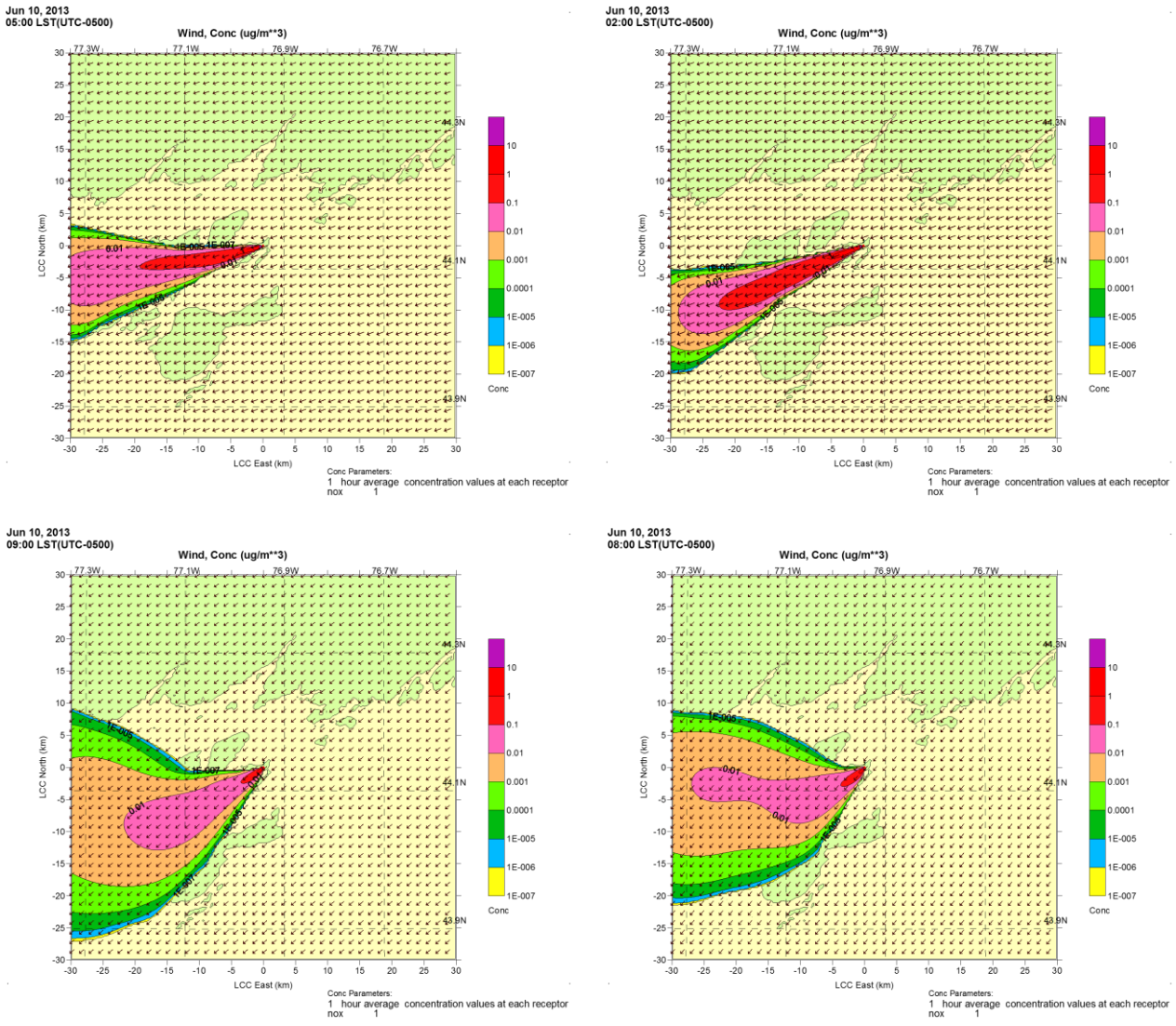

Figure 6. NO_x emission dispersion in the summertime

Table 6 shows the top 10 (1 hour, half hour and 24 hour) concentrations for the dispersion of NO_x, and SO_2 in the wintertime while Table 7 shows the same results for the summertime.The results indicate that none of the concentrations exceeded the limits set by Ontario regulation 419/05, which are 500 µg m^{-3}, 400 µg m^{-3} and 200 µg m^{-3} for half hour, 1 hour and 24 hour averaging periods respectively for NO_x and 830 µg m^{-3}, 690 µg m^{-3} and 275 µg m^{-3} for half hour, 1 hour and 24 hour averaging periods respectively for SO_2. The Ministry of Environment standards can be seen in Table 5.

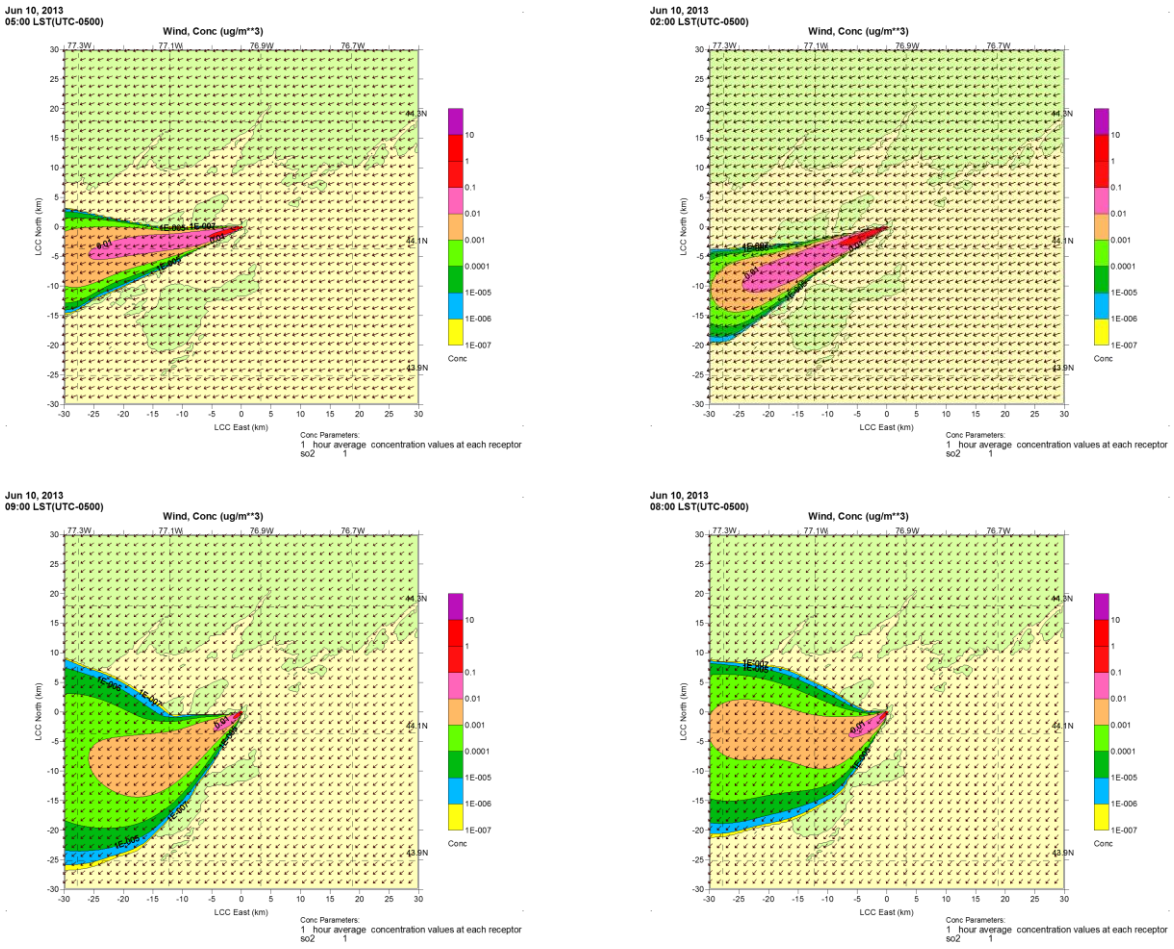

Figure 7. SO_2 emission dispersion in the summertime

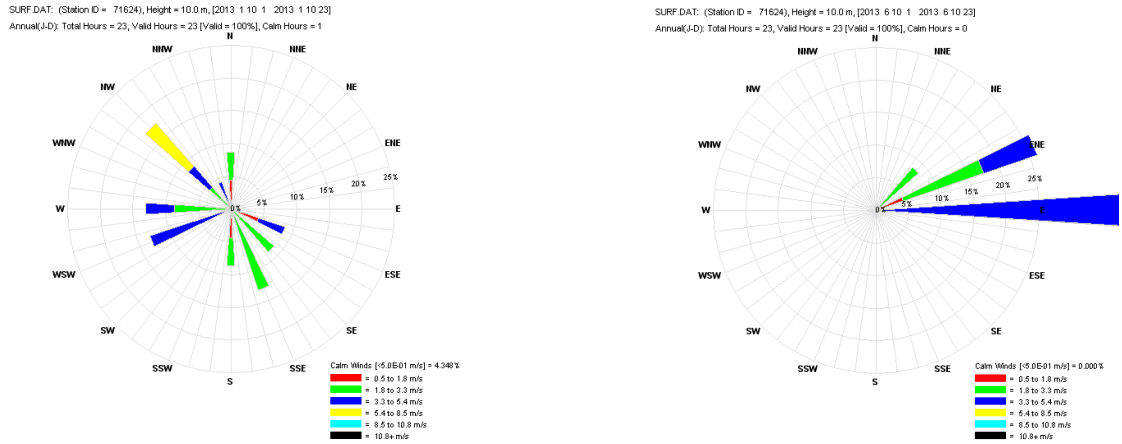

Figure 8. Windrose diagrams for January 10, 2013, and June 10, 2013

Using of a biogas as a fuel source is the target of some intensive research. In this paper, the landfill that is located in Napanee in Ontario (Canada) will be used to produce biogas from organic matter. The produced

gas will then be used as a fuel source to an onsite generator that will be used to generate onsite electricity for the landfill mechanisms. In the construction of this biogas producing plant, an assessment of the environmental impacts of the process is needed. This study intends to provide insight on the nitrogen oxides and sulfur dioxide emitted from the plant, their dispersion behaviors and the effects they may have on the immediate environment. This information would prove invaluable to further research on the impacts of the process on the environment.

4. Conclusion

This case study made use of the CALPro modeling system to model emission dispersions of NO_x and SO_2 air contaminants from a generator and flare in a biogas producing plant in the town of Napanee. The operation of the facility will not have adverse effects on human health as the emissions are below the allowable healthy standards prescribed by the Ministry of Environment's Ontario regulation 419/05. Other nearby receptors to the facility will also most likely not be endangered by emissions from the facility. The concentrations of NO_x and SO_2 during operations of the proposed biogas producing facility were both determined to be well below Ontario's regulation limits, such that they do not pose a threat to human health, society and the environment. Thus, there were no potential hazards identified with the existence and operation of the facility.

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Declaration of conflicting interests

The authors do not have any potential conflicts of interest to declare.

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